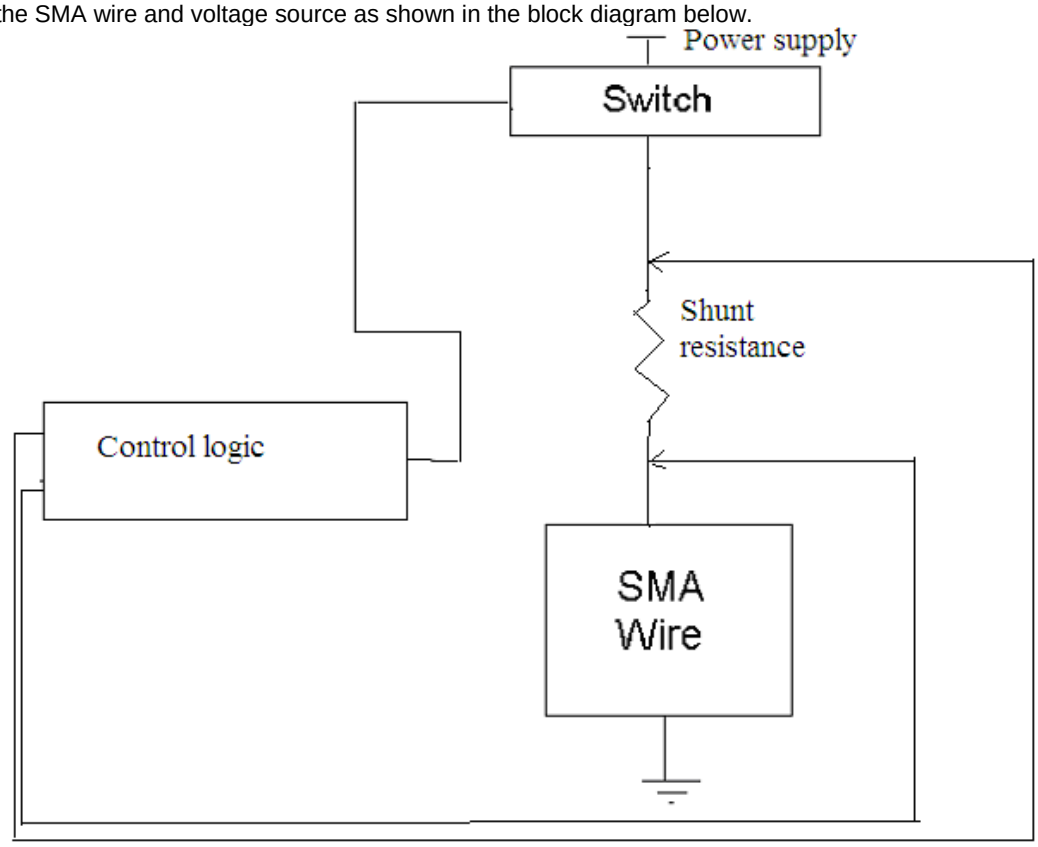
User manual for SMA tester

The SMA wire tester developed is used to control the instantaneous power supplied to the SMA wire under test. The two primary goals of the system are as follows:-

1. Power regulation of the DUT according to a prescribed power signal.
2. Continuous resistance measurement of the device under test.

The resistance of Shape memory alloy wires is dependent on the strain and the temperature hence complicating power management. Continuous resistance measurement is critical to study the behavior since this data gives us valuable information about the state of the wire. In the past the concept of Pulse Width Modulation (PWM) has been used to control the power by switching on and off a switch connected between the SMA wire and voltage source as shown in the block diagram below.



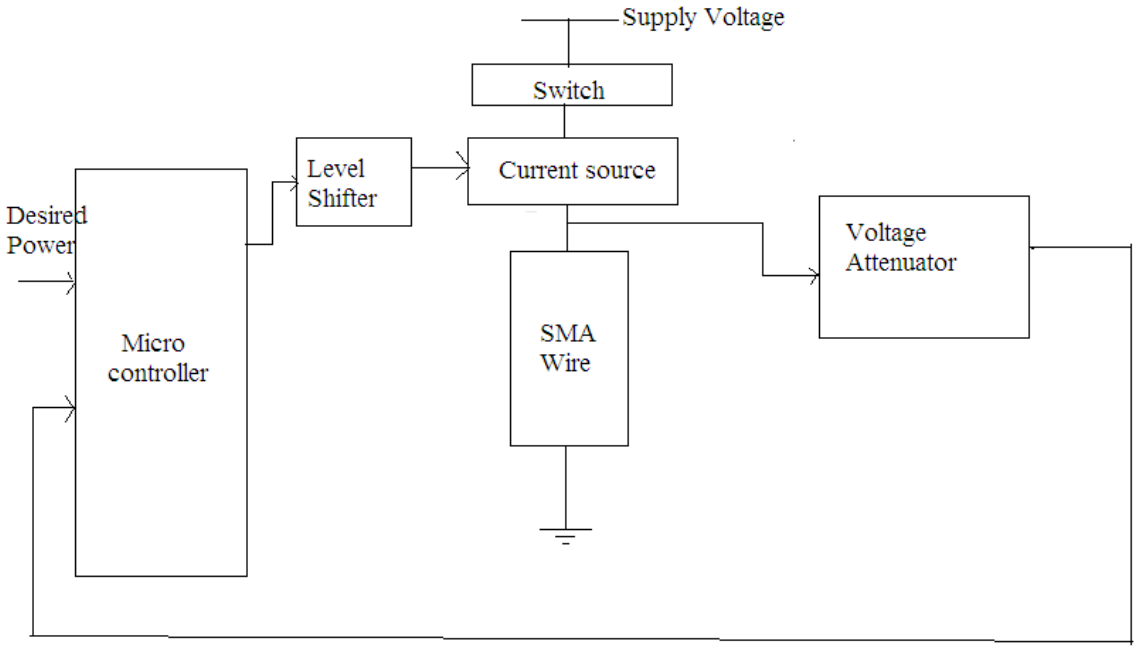
This design of the system required an addition small shunt resistance in series to monitor the instantaneous current flowing through the SMA in addition to the voltage monitor across the SMA wire. These two signals are fed to a control logic, which adjusts the duty cycle by switching the switch on and off. Traditionally the control logic is implemented using analog components and the performance deteriorates at very high and low duty cycle.
In addition to this the resistance measurement is taken periodically by stopping the PWM cycle and applying the fixed voltage for small duration of time and then taking the resistance measurement using the voltage across SMA and the current flowing.
The above design is flawed since the resistance measurement is not continuous and there is also an unnecessary use of shunt resistance and added voltage drop across the same. The periodic measurement of the resistance also requires a trigger signal to initiate the measurement process, stopping the current cycle, which means small distortions in the power delivered, and all this adds to the complexity of the system.

Now coming on the new system developed, it is also based on Pulse width modulation but instead of using a voltage source this system uses a constant current source to power the SMA wire. The advantage of using a constant current source over the voltage source is that there would be no need to add an additional shunt

resistance. By looking at the voltage across the SMA we can directly calculate the resistance since current is consant,

$$R_{measured} = V / I_{constant}$$

The block diagram of the system developed is as follows:-



In this system, the concept of Pulse Width Modulation is used to control the instantaneous power delivered to the SMA wire. As seen in the figure, a switch implemented using N channel MOSFET is used to switch on and off the power supply. When the current source is on, it supplies a preset constant value of current and hence this would give us a waveform as shown below across the SMA.

The high level voltage is given by

$V = R_{SMA} * I_{constant}$

The ratio of the duration of the time the pulse is high to that of the duration of the time the pulse is low is known as the duty cycle of the pulse.

η (duty cycle) = T_{high}/T_{low}

The instantaneous average power seen by the SMA over the period of 1 pulse width can be easily calculated as

$P_{avg.} = V_{high} * \eta$

The above described is the basic idea involved in the design of this SMA tester.

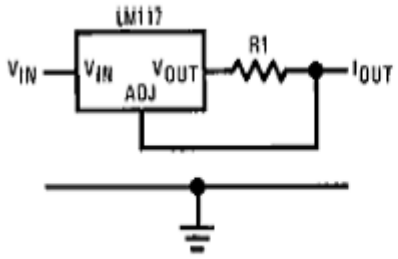
The two goals of the system can be simultaneously achieved by the use of a constant current source since switching the same on and off using PWM would adjust the power. In other words, the duty cycle of the pulse can be used to adjust the power levels. Also, due to the fact that current is constant, continuous monitoring of voltage would result in continuous current monitor.
This concept is better than the age old concept of using voltage source since it does not require the use of a shunt resistance for monitoring current which would have been needed for resistance measurement otherwise.

Now we will discuss each component in detail: -

Level Shifter:-
The output PWM voltage from the micro controller is in digital forms ie. It has 2 levels namely 0V and 5V. To make this voltage switch the N channel MOSFET switch it would have to be shifted to 0V and Vp^+ since the supply voltage is Vp^+
To implement this block a non-inverting amplifier with a large gain is used. The circuit diagram is as follows:-

Switch:-
The switch is implemented using N channel MOSFET where the gate is connected to the control signal, drain is connected to the power supply and the source acts as the output connected to the input of the current source.

Current Source:-
LM117 is used as the current source in the following configuration.



$$I_{OUT} = \frac{1.25V}{R1}$$

$10\ mA \leq I_{OUT} \leq 1.5A$

TL/H/7334–5

FIGURE 5. 2-Terminal Current Regulator

The voltage regulator LM117 ensures that the voltage between V_{out} terminal and ADJ terminal is always equal to 1.25V. So, a potentiometer could be used in place of R1 and we have a current source which can be set by turning a knob. The current equation is given above as long as the current is less that 1.5A

Voltage attenuator
The voltage across the SMA can go as high as 12V but the input to the ADC ports of the micro controller should be restricted to only 5V. Hence we should use a voltage attenuator with adjustable gain to ensure that the input to the ADC port is restricted to 5V.

Micro controller: -
We have implemented this system using ATMEGA324 micro controller and this component is responsible for decision making and adjusting the PWM duty cycle. The micro controller takes in 2 analog inputs. On channel 0 the voltage across the SMA after the voltage attenuator is fed and the other channel is connected to the power control signal.
The micro controller runs at a frequency of 1 MHz and it uses 10 bit counter for PWM and hence the PWM cycle frequency is approx. 1KHz. The fundamental principle of the system is to set the next duty cycle based on the resistance of the SMA measured in the previous cycle.

The basic concept of the PWM cycle is based on the fact a pulse can have 2 levels:-

1. High
2. Low.

The width of the high level/low level determines the power supplied to the SMA. For instance if the high level voltage is x volts at a constant current of y Amps with a duty cycle of z the power supplied at this moment is:-
Power= x*y*z Watts.
In other sense if we wish to set a power P_{set} at an instant and given the fact that the SMA cannot respond at 500Hz we can set the duty cycle as:-
Duty cycle= P_{set} /(resistance*current*current).

The micro controller runs the ADC in free running mode with timer overflow as the interrupt. Timer overflow occurs at the end of each cycle/start of next cycle so after 16μs of the start of the new cycle the value of the voltage across the SMA is sampled. This insures that we always sample the high level voltage provided the duty cycle is greater than 1.6%. Once the voltage is sampled, the above formula can be used to set the duty cycle of the next cycle.

This calculation is done in the background with the ADC capture occurring on timer overflow and the timer overflow interrupt is used to update the value of the new duty cycle into the corresponding register. The value of P_{set} is also taken as input from the ADC channel and is continuously updated to set the duty cycle. P_{set} is an analog voltage signal between 0 and 5 volts hence a scaling factor is introduced to get the specified resolution since ADC has a precision of 10 bits which gives us a precision of 4.8 mV. So if scaling factor is x,

Precision of desired power level = 4.8/x mW;

But in practice the LSB of the micro controller is not stable hence a precision of 10/x mW is achieved.

Inputs and Outputs:-

1. V_{p+}, V_{p-}, V_{gnd} :- Power supply connections. The max. allowable voltage specifications for the system are +20V and –20V.
   If the desired voltage across the SMA<12V Astrodyne power supply with +15V and –15V would work but if the voltage across SMA exceeds 12V switch over to +20V and –20V.
2. V_{cntr} :- The voltage signal to set the instantaneous power to the SMA. This signal is connected to the ADC port of the micro controller so the max. voltage that can be given is 5V. So, to accommodate this fast we have a scaling factor.

   So, V_{cntr} = Scaling factor * Desired power (in Watts).
   So, if the maximum power desired is x Watts then the scaling factor should be calculated as
   Power scaling factor=5/x.

   The scaling factor should not be too low otherwise low power levels could not be achieved since the ADC port of the micro controller has 10 bits of resolution. So, minimum resolution of the
3. DUT^+ and DUT^- :- These are the terminal leads to connect the SMA wire to be tested.
4. V_{out} / DUT^+:- This signal is the output voltage waveform seen by the SMA and can be used for both power validation and resistance measurement.
5. $V_{trigger}$:- This signal is to be used as a digital trigger source for the acquisition system.
6. $V_{micro\text{-}controller}$:-This is the input to the ADC port of the micro controller. The voltage waveform across the SMA is fed to a voltage attenuator and then given to the micro controller to ensure that the maximum voltage reached across the micro controller is 5 V.

<u>Working of the system:-</u>

System specifications:-

Constant current source:- The maximum reliable current that could drive the actuator is 400mA. The current value can be set using the 2 potentiometers and this should be set as increments of 10mA. So, allowable values are 10mA, 20mA and so on upto 400mA.

Voltage across the SMA:- With split power supplies of 15V the maximum voltage across the SMA can go to 12V. So, for higher voltages switch to 20V split power supply.

Power levels:- The power is a function of resistance and the set constant current. If the maximum possible resistance value for the SMA is R ohms and I Amps of current is used to drive it then maximum power attainable is :-

$P_{max.} = I*I*R$

Duty cycles:- The current duty cycle is calculated as follows:-

λ (duty cycle) = Pset/ (I*I*R)

Resistance :- The maximum resistance than this device can drive depends on the max. voltage across the resistance. So, maximum voltage for 15V power supply is 12V so maximum drivable resistance = 12V/ I constant .

Due to the rise time and fall time ensure that duty cycle never goes below 3 %.

So, minimum allowable power= (I*I*R)*.03 Watts

If the prescribed duty cycle somehow is >100% the register in the micro controller overflows and the set duty cycle is (prescribed- 100)%. So, to avoid this ensure that the duty cycle is never above 98%.

Frequency of the power signal:- The power voltage is sampled at the frequency of 500 Hz so according the frequency of the power signal can be set. A frequency of 30 Hz is easily attainable.

Signal acquisition for output measurement:-

V_{out} is the output signal which can be used for both resistance measurement and power validation. $V_{trigger}$ is the digital signal which can be used to trigger the data acquisition since to accurately measure the power we have to ensure that we get the correct window of the PWM cycle. So, using the rising edge of the trigger signal 101 samples can be acquired at 100KHz to get 1 full window of PWM.

Resistance measurement: - The resistance is measured by just acquiring the peak voltage value or the plateau value which gives the instantaneous voltage across the SMA when we are in on state and diving it by value of current would give us the instantaneous resistance value.

$$R_{measured} = V_{peak} / I_{constant}$$

So resistance can be measured at the rate of 1 KHz.

Power validation:- Power can be validated by acquiring the correct window as described earlier and then taking the average DC value and multiplying it by value of current.

$$P_{validated} = V_{avg} * I_{constant}$$

Calibration and Settings:-

1. Setting the value of current:-
    a) Connect a fixed resistor across DUT^+ and DUT^- whose resistance is in the range of the nominal resistance of the SMA wire. The current source is stable to a large extend in certain windows so it is advisable to connect an appropriate resistor across DUT^+ and DUT^- for setting the current.
    b) Set the toggle switch TS1 in initialization mode.
    c) For using Trimmer 1(TR1) switch TS2 and TS3 in position corresponding to TR1 and similarly for (TR2). The switched TS2 and TS3 should be always in the same position to ensure that either TR1 or TR2 is properly connected. For current less than 140mA use TR1 and for greater current use TR2.
    d) Using a screwdriver adjust the trimmer to obtain the desired current values by measuring the voltage across the test resistor. Since the value of resistor is know the voltage across the resistor should be:-

$$V = I_{set} * R_{known}$$

2. Setting the value of voltage attenuator/voltage scaling factor (TS1 in initialization position)
    a. Once the current is set connect the voltmeter across $V_{micro\text{-}controller}$ terminal and use TR3 to set the desired value of voltage attenuator. The value of voltage attenuator should be set appropriately since the maximum permissible voltage across the ADC pins of micro controller is 5V and if higher it may burn the ADC ports. So,

    Voltage scaling factor = (max. Voltage across SMA)/ 5.

    The voltage-scaling factor should be an integer value such as 2, 3 or 4.

To be on the safer side, first connect a smaller resistor across DUT^+ and DUT^- terminals and adjust the voltage attenuator using step 2 to the desired value as calculated above. Then set the current as described in step 1 and then again fine-tune the value of voltage attenuator as in step2. The step 2 is again done to ensure that the value of scaling factor hold good in this voltage range and small non-linearity of voltage attenuator is also taken care of. Instead of this if suppose the voltage attenuator is preset at a lower value and the current is high and voltage across the fixed resistor/ scaling factor exceeds 5V, the ports of ADC might burn.

3. Setting the values of power scaling factor, voltage scaling factor and current value in the micro controller.

The DIP switch and the button PS1 are used to input the values into the micro controller. The DIP switch has labels 1,2,34,5,6,7 and 8. Switched in on position inputs binary 1 into the pin and off position inputs binary 0.
Bits 7 and 8 are used to define what variable we wish to input.

Bit 7	Bit 8	Variable name
0	0	Constant current
0	1	Voltage scaling factor
1	0	Power scaling factor
1	1	No input

The value that we wish to input into the particular variable is as follows:-

a) Constant current:- Bit 1 to Bit 6 are used to input the values. So, if we wish to input x milliamps, divide this by 10. This value is then written in binary form and then it is fed with Bit 1 being the least significant bit and Bit 0 being the most significant bit. So we have values of current on increments of 10mA upto 400mA.
b) Power scaling factor:- Bit 1 to Bit 6 are used to input the values. So, if we wish to input x , multiply this by 2. This value is then written in binary form and then it is fed with Bit 1 being the least significant bit and Bit 0 being the most significant bit. So, the values can be increments of .5 and maximum possible value is 128.

c) Voltage scaling factor:- Bit 1 to Bit 6 are used to input the values. So, if we wish to input x write in binary form and then it is fed with Bit 1 being the least significant bit and Bit 0 being the most significant bit.

Once the appropriate switches are set, push the push button PS1 once and the respective variable is set into the micro controller. Similarly do this for the three variables ie. set the DIP switches and then push PS1 once. To be sure, push it two or three times for each variable. The value is retained in the micro controller until the power supply is on or push button PS2 (red color) is pushed. PS2 is reset push button which resets the micro controller to the default setting.
The default setting for the micro controller are as follows:-

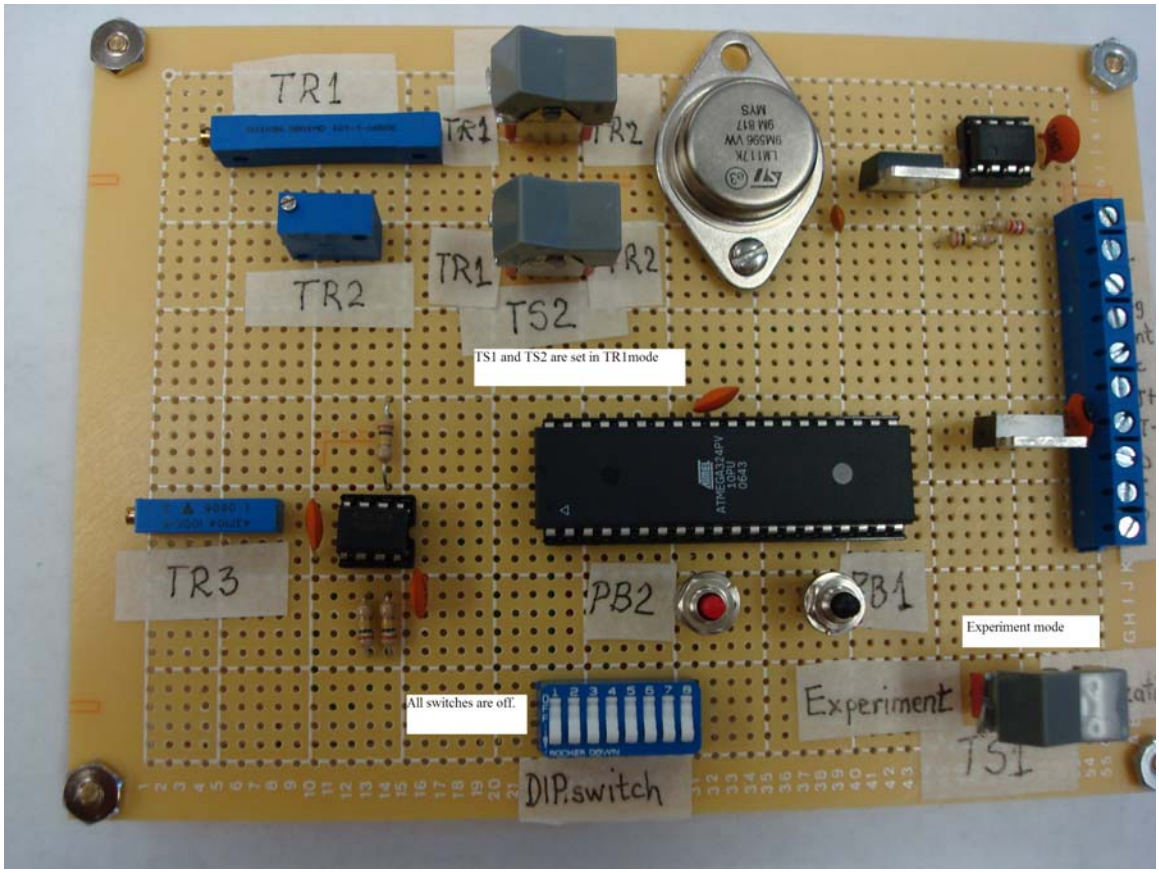
1. Current value:- 180 mA
2. Power scaling factor:- 5
3. Volatage scaling factor:- 2

If a wrong value fed in push PS2 and the micro controller returns into the default state.

Table showing the inputs to the DIP switch

Bit 1	Bit 2	Bit 3	Bit 4	Bit 5	Bit 6	Bit 7	Bit 8	Variable	Value
0	0	0	0	0	0	0	0	Current	0 mA
1	0	0	0	0	0	0	0	Current	10 mA
0	1	0	0	0	0	0	0	Current	20 mA
1	1	0	0	0	0	0	0	Current	30 mA
0	0	1	0	0	0	0	0	Current	40 mA
1	0	1	0	0	0	0	0	Current	50 mA
0	1	1	0	0	0	0	0	Current	60 mA
1	1	1	0	0	0	0	0	Current	70 mA
0	0	0	1	0	0	0	0	Current	80 mA
1	0	0	1	0	0	0	0	Current	90 mA
0	1	0	1	0	0	0	0	Current	100 mA
1	1	0	1	0	0	0	0	Current	110 mA
0	0	1	1	0	0	0	0	Current	120 mA
1	0	1	1	0	0	0	0	Current	130 mA
0	1	1	1	0	0	0	0	Current	140 mA
1	1	1	1	0	0	0	0	Current	150 mA

Once the calibration is done just put PS1 into experiment mode position and start the experiment.


TR1
TR1
TR2
TR2
TR1
TR2
TS2
TS1 and TS2 are set in TR1mode
TR3
PB2
PB1
Experiment mode
All switches are off.
Experiment
TS1
DIP.switch